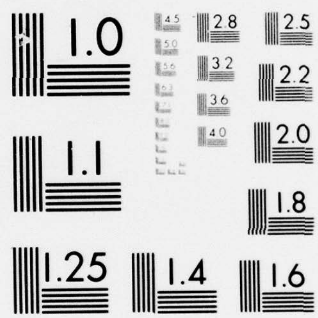
AD-A056 362 NAVAL RESEARCH LAB WASHINGTON D C F/G 20/9
TIME DEPENDENT ELECTRON AND ION FLOW IN PINCHED BEAM DIODES.(U)
MAR 78 R LEE, S A GOLDSTEIN MIPR-78-523
UNCLASSIFIED NRL-MR-3702 SBIE-AD-E000 170 NL

| OF |
AD A056362

END
DATE
FILMED
8 -78
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6

ADA056362

adu000170

NRL Memorandum Report 3702

Time Dependent Electron and Ion Flow in Pinched-Beam Diodes

ROSWELL LEE

Plasma Dynamics Branch
Plasma Physics Division

and

SHYKE A. GOLDSTEIN

Science Applications, Inc.
McLean, Virginia

LEVEL II

March 1978

This research was sponsored by the Defense Nuclear Agency under Subtask T99QAZLB203, Work Unit Code and Title 12/Advanced Concepts Theory MIPR No. 78-523

NAVAL RESEARCH LABORATORY
Washington, D.C.

Approved for public release; distribution unlimited.

78 06 16 009

18 SBIE

19 AD-E000 170

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 3702 (14 NRL-MR-)	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) TIME DEPENDENT ELECTRON AND ION FLOW IN PINCHED-BEAM DIODES.		5. TYPE OF REPORT & PERIOD COVERED (9) Interim report on a continuing NRL Problem
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Roswell Lee [redacted] Shyke A. Goldstein		8. CONTRACT OR GRANT NUMBER(s) (17) B203
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem No. 77H02-26K DNA Subtask T99QAXLB203 (16)
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Nuclear Agency Washington, D.C. 20305		12. REPORT DATE (11) March 1978
		13. NUMBER OF PAGES 17 (12) 19p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (15) MIPR-78-523		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This research was sponsored by the Defense Nuclear Agency under Subtask T99QAXLB203, Work Unit Code and Title 12/Advanced Concepts Theory MIPR No. 78-523.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Pinched-beam diode
Electron flow
Ion flow
Impedance relativistic electron beam

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The time dependent impedance behavior of large-aspect-ratio, pinched-electron-beam diodes is studied using a computer simulation model. The results from a series of particle code simulations are used to construct a picture of the diode impedance as a function of voltage. This description is then used to compare calculated diode current with actual measured values, and good agreement is found. The code is also used to study dynamic pinch formation and ion current generation. A focusing model for the ions is presented.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

~~78 06 16 009~~

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

25 | 950 CL

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

CONTENTS

INTRODUCTION 1

DIODE IMPEDANCE 2

TIME DEPENDENT PINCH FORMATION AND
ION GENERATION 6

CONCLUSION 8

ACKNOWLEDGMENTS 8

REFERENCES 8

TIME DEPENDENT ELECTRON AND ION FLOW IN PINCHED-BEAM DIODES*

INTRODUCTION

In order to gain a better understanding of the dynamic processes taking place in high-aspect-ratio pinched-beam diodes, a two-dimensional computer simulation code DIODE2D[1] has been developed to study these processes for a wide range of diode parameters. This code, which follows the relativistic dynamics of electrons and ions coupled to their self-consistent electric and magnetic fields, contains a fully time-dependent emission scheme which allows time dependent diode phenomena to be studied. Figure 1 shows the diode geometry used in the simulations. Both flat faced and hollow cathodes were simulated. For flat faced cathodes (Fig. 1a) electrons are emitted self-consistently all along the whole cathode (K) while for hollow cathodes (Fig. 1b) electrons are emitted only over a region of radial width ΔR. Since the version of the code used in these studies allowed only a rectangular simulation region, the potential along the remaining segments of the boundary was graded to emulate the actual geometry. Emission of the ions from the anode (A), also self-consistent, was usually over its full face out to the outer radius of the cathode.

In this report, we first look at a composite picture of the impedance of the diode which is the result of many simulations. This description of the impedance is then used to analyze experimental data from two representative shots, one taken on Gamble I and the other taken on Gamble II. The diode current for the shots is calculated as a function of time using the experimentally measured corrected voltage as an input parameter. The calculated currents are then

Manuscript submitted January 18, 1978.

compared to the measured currents for the two shots.

The dynamic details of one of the simulations used to construct the impedance picture is then presented. The collapsing hollow ring and pinch formation are shown, as well as, the total diode current and ion current as a function of time. We then model and show the projected ion focus.

DIODE IMPEDANCE:

In our numerical studies the primary goal at this stage was to determine the impedance of the diode as a function of various diode parameters. Limitations of computational speed make it impractical to stimulate the complete time history (50-100 nsec) of the pinched-beam diode. Simulations describing 5 nsec of real time can be calculated, however, and this is sufficient time for an ion induced pinch to form for diodes with radii less than approximately 10 cm if the dynamics of cathode and anode plasma generation are ignored. We will assume that at the beginning of the simulation both the cathode and anode plasma exist over all or some part of the cathode or anode. This control of the actual emission regions is used to model the regions where actual plasma generation and electron/ion emission take place. In the emission regions the electrons and ions are emitted in a time dependent, space-charge-limited manner. The electron and ion dynamics are then followed until a quasi-steady state is reached, if ever. It should be noted that in some of the data presented here the simulations did not reach a steady-state although the total current reached a quasi-steady value.

Two types of diodes were studied. The first has a full, flat faced cathode with a maximum radius, R, of 5 cm and R/D's from 4 to 30, where D is the gap spacing. The second is a very hollow, flat faced cathode with R of 6.4 cm, $\Delta R/R$ of 0.11, and R/D of 20. Here ΔR is the radi-

al width of the emitting surface on the cathode. Both diodes were simulated for cases with both electron and ion currents and then electron current only. The total current for one diode in which ions were emitted only from $R = 0$ to $R = 3/4R$ was also calculated at an R/D of 10. Figure 2 shows a plot of the total diode current scaled by D/R as a function of voltage for each of these diodes. The dashed lines connect results obtained at an R/D of 20. The closed and open squares represent data for a solid cathode with and without ion current. The shaded region connecting triangular points represents the computed diode current for a hollow cathode with $\Delta R/R$ *of* 0.11. The upper bound in this case being for electron plus ion current while the lower bound in this case being for electron plus ion current while the lower bound is that for electron current only. The plus symbol represents the calculation for the case where the ion emission was only for radii smaller than 3/4 R. Also plotted for reference in Fig. 2 are the saturated parapotential current 8.5 $(kA)\ \gamma \ln\ [\gamma + (\gamma^2 - 1)^{1/2}]\ R/D$ (curve PP) and the critical current for self pinch 8.5 $(kA)\ (\gamma^2 - 1)^{1/2}\ R/D$ (curve CC) curves.

In the upper half of Fig. 3 the experimental voltage and current curves are shown for shot 5707 on Gamble I. The very hollow cathode used had an outer radius of 42 mm and a radial emission width of 7 mm. After whisker exposion the corrected gap was taken to be 3 mm and an average plasma closure velocity of 1.8 cm/μsec was inferred from an analysis using the so called "semi-emperical" current formula.[2] The lower half of Fig. 3 shows the effective gap and the measured impedance as a function of time. The initial plasma motion is assumed to be correlated with the onset of the current and hence delayed somewhat from the voltage rise. The gap, as a function of time, is given by $D\ (T) = 3.0 - 0.018\ (T - 9)$, where D is in millimeters and T is in nanoseconds.

Figure 4 shows the voltage, current, and impedance curves for shot 1776 on Gamble II. Another very hollow cathode was used with an outer radius of 65 mm and a radial emission

width of 4 mm. The initial corrected gap was taken to be 4.4 mm and the average plasma closure velocity, calculated from the time to short circuit, was 4.0 cm/μsec. The gap, as a function of time, is then given by $D\ (T)\ = 4.4\ - 0.04\ (T\ - 10)$.

Table 1 gives a summary of the important parameters for the two shots. Shot 5707 was analyzed for times from 40 nsec to 100 nsec while shot 1776 was analyzed from 40 nsec to 100 nsec. T_p is the time at which the pinch was formed on axis. The effective R/D varied with time as the gap closed. In shot 5707 R/D was 20 at 40 nsec and became infinite when the diode sorted out. Since all the simulations for hollow cathodes were at $R/D\ = 20$ it is implicitly assumed that to lowest order the current, at a fixed voltage, increases linearly with R/D. This seems to be true for the very hollow cathodes.

In Fig. 5 the normalized current versus the corrected voltage is plotted for the two shots. The upper dashed line is the total current, electron plus ion, for the $R/D = 20$ very hollow cathode simulations given in Fig. 2. The lower dashed line is the electron only current from the same simulations. The two curves plotted on the upper part of the figure are the evolution in time of the normalized current versus voltage for the Gamble I and Gamble II shots. The arrows along the curves point in the direction of the advancement of time. The vertical arrows indicate the time at which the pinch arrived on axis. In the analysis of the data the linear gap closure model discussed previously was used.

Since ion flow in the diode is necessary for pinch formation,[3] one would expect full electron and ion flow to have developed at about the time the pinch forms on axis. The voltage-current characteristics would then be expected to follow the upper dashed curve on the figure. Shot 5707, the Gamble I shot, follows the simulation curve remarkable well shortly after the pinch forms on axis. The data for the Gamble II shot, 1776, although in the general vacinity is somewhat lower than the predicted value.

The key feature in the analysis of the data is the model for the gap closure. The experimental data cannot be analyzed directly since the gap, as a function of time, cannot be measured directly. In order to compare the experimental data with the simulations we must somehow model the dynamics of the gap. Of all the areas of diode physics the formation of the cathode plasma by whisker explosion and its subsequent motion is probably the least understood. It is usually assumed that in the first few nanoseconds of the pulse the field emission current flowing in the cathode whiskers heats them until they explode forming a cathode plasma sheath. The formation of the sheath and its resultant expansion velocity seems to depend critically on the initial rise-time of the electric field.[2,4] For lack of any better idea one usually trys to find the average expansion (closure) velocity. This seems to work fairly well with the lower power machines such as Gamble I and, hence, the good agreement in Fig. 5.

On Gamble II, however, there are other competing mechanisms: namely, the heating of the cathode by electrons returned by the time dependent electromagnetic fields due to inductive effects in the diode, and from ion current striking the cathode with current density inversely related to the diode gap and radius. Both of the mechanisms could increase the closure velocity as a function of time. In light of these effects, we have investigated a simple model where we arbitrary assume that the plasma velocity increases linearly in time from some initial value. The difference between the average value, which can be calculated from the time of the short circuit, and the initial value is a parameter in this model. Figure 6 shows a comparison between the constant velocity model and the linearly increasing velocity model. The difference between the two models, since both have the same average velocity, is that the gap closes more slowly at first in the latter. Using a value of α equal to 0.5, we have re-analyzed shot 1776 and the results are seen in the lower figure on Fig. 5. Using this model then gives a much better fit of the experimental data to the simulation results. This, of course, in no way

proves that the gap closes in a nonlinear fashion but since there is other evidence for the previously discussed mechanisms this just re-enforces ones belief that plasma gap closure is a complicated and not very well understood phenomenon.

TIME DEPENDENT PINCH FORMATION AND ION GENERATION:

In this section details of the time dependent formation of a pinch from a very hollow cathode are presented. The parameters for the simulation are as follows: the diode voltage, 750 kV, the outer radius of the cathode, 6.4 cm, the radial width of the emitting surface, 7 mm, and the anode-cathode gap was 3.2 mm. Ions were emitted over the whole anode out to the maximum cathode radius. Figure 7 shows the diode geometery and a composite picture of the electron current density collected on the anode plane as a function of time. The collapsing hollow ring, which reaches the axis and forms the pinch in about 2.5 nanoseconds, is clearly seen. Although the peak current density in the pinch region is extremely high, of the order of 1.6 MA/cm^2, only about 40 kA of total electron current are contained within the pinch. The pinch itself was not stable in this simulation but would disappear soon after forming. Then at some intermediate radii, between 2.5 - 4.5 cm, one or two hollow rings would reappear. They would then collapse in about 1.5 to 2 nanoseconds to re-form the pinch.

The small peak in current density at large radii is most probably due to electrons emitted from the inside edge of the cathode. The maximum of this peak is a current of about 15 kA/cm^2 and amounts to a current of about 60 kA, or more than that in the pinch itself. The remaining current, approximately 250 - 300 kA is spread out more or less uniformly in radius over the anode.

The total diode current and the ion current collected on the cathode are shown in Fig. 8 as a function of time. The first thing to take note of is that the total diode current remained very steady for the duration of the simulation at a value of about 550 kA. On the other hand the ion current, and hence the electron current also, oscillated in time. The average value of the ion current was around 140 kA giving an average ion current to electron current ratio of 1/3. The ion current, which would peak some 0.2 - 0.3 nanoseconds before the pinch formed on axis, had maximum values near 170 kA.

In Fig. 9 the density of ion current collected by the cathode, at the time of the first maximum of the total ion current, is plotted as a function of radius. This figure is representative of the ion current density during the collapse of the electron hollow ring on the anode. The peak of the ion current density, which has a value of about 9 kA/cm^2, is located at the radial position that the electron ring had on the anode when the ions were emitted, some 0.4 nanoseconds earlier. The average ion current density over the whole cathode is $\sim 2\ kA/\mathrm{cm}^2$.

We now use the results of this simulation to model the ion focusing by a shallow spherical anode with a radius of curvature of 12.5 cm. The planar geometry used in the simulation was mapped into the spherical dish geometry used in the acual experiments.[5] The ion orbits calculated by the code were then geometrically projected into the region outside of the non-emitting portion or the cathode. The variation of ion directions at the cathode, about 2 degrees, were taken into account when the projections were calculated and the ion current density was averaged over a complete oscillation period. Figure 10 now shows the axial variation of the radial current density profiles as one moves to either side of the anticipated focal position. At the focus the peak current density of $\sim 60 kA/\mathrm{cm}^2$ is over a radius of about 4 mm. Also, notice that while the current density at large radii is small it contains about 75% of the total ion

current (120 kA time averaged). Some of this current could be brought into focus by using aspheric surfaces. However, time dependent fluctuations will probably put a limit on the smallest focal size attainable.

CONCLUSION:

We have shown that the time dependent impedance of the diode can be reasonably interpreted using the results of the computer simulations. And, that pinch formation and other dynamic processes that take place in relativistic pinch-beam diodes can be studied in detail.

ACKNOWLEDGMENTS

The authors wish to thank D. J. Johnson for many useful discussions.

*Work supported by the Defense Nuclear Agency, Washington, D.C. 20305

REFERENCES

1. R. Lee and S.A. Goldstein, NRL Memorandum Report (to be published).
2. D. J. Johnson, S.A. Goldstein, R. Lee, and W. F. Oliphant, NRL Memorandum Report (to be published).
3. S.A. Goldstein and R. Lee, Phys. Rev. Lett. **35**, 1079 (1975).
4. R.K. Parker, R.E. Anderson, and C.V. Duncan, J. Appl. Phys. **45**, 2463 (1974).
5. D. Mosher, G. Cooperstein, S.J. Stephanakis, S.A Goldstein, D.G. Colombant, and R. Lee, in Proceedings of the 2nd International Conf. on Electron and Ion Beam Research and Technology, Cornell Univ., Ithaca, New York 1977 and NRL Memorandum Report No. 3658, November 1977. S.A Goldstein, G. Cooperstein, R. Lee, D. Mosher, and S.J. Stephanakis, NRL Memorandum Report (to be published).

Table 1

SHOT 5707	SHOT 1776
G I	G II
Vmax= 430 KV	Vmax= 700 KV
Imax= 340 KA	Imax= 690 KA
R = 42 mm	R = 65 mm
ΔR= 7 mm	ΔR= 4 mm
D = 3 mm	D =4.4 mm
40 - 100 nsec	40 - 110 nsec
Vo= 1.8 cm/μsec	Vo= 4.0 cm/μsec
R/D 17 - 31	R/D 20 - ∞
Tp= 50 nsec	Tp= 40 nsec

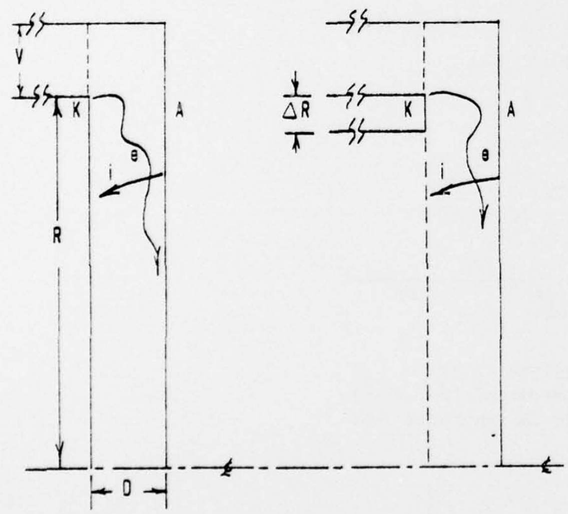


Fig. 1 — Diode geometry for simulations

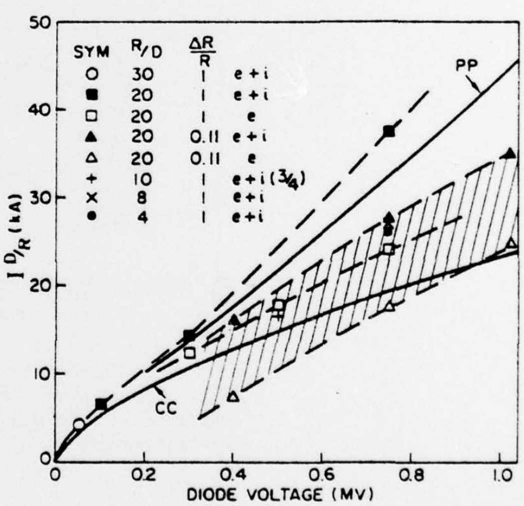


Fig. 2 — Total diode current normalized by *D/R* as a function of diode voltage. The parapotential current (PP) and critical current (CC) are also shown for comparison.

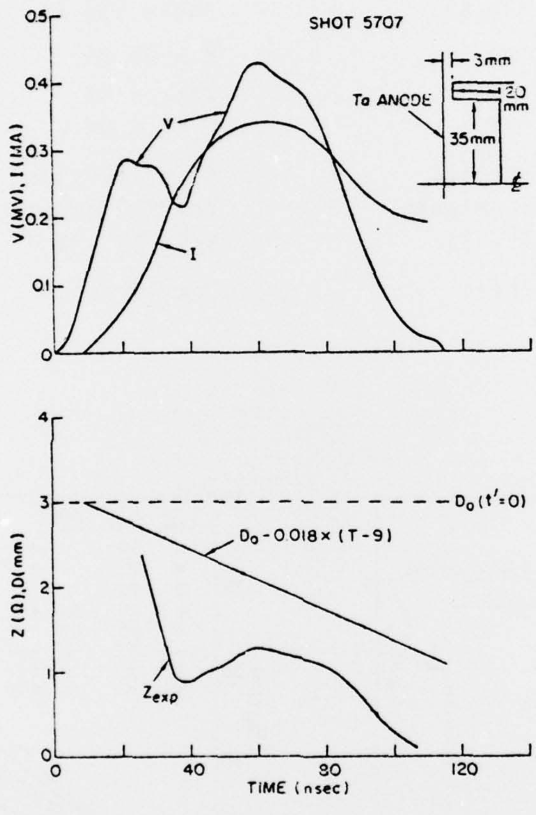


Fig. 3 — Corrected diode voltage and current for shot 5707. In lower graph the experimental value of the impedance is shown along with the gap closure used to reduce the data.

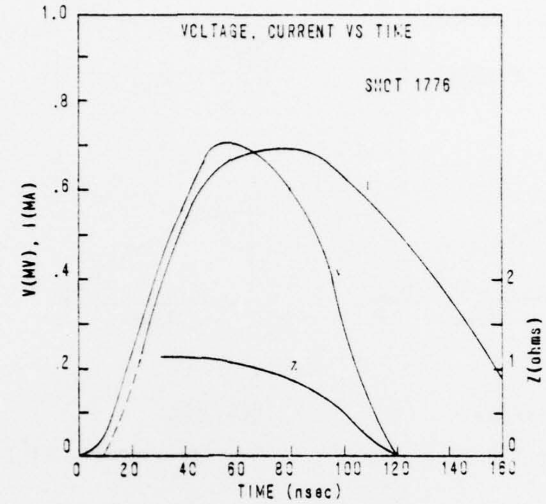


Fig. 4 — Corrected diode voltage, current, and impedance versus time for shot 1776.

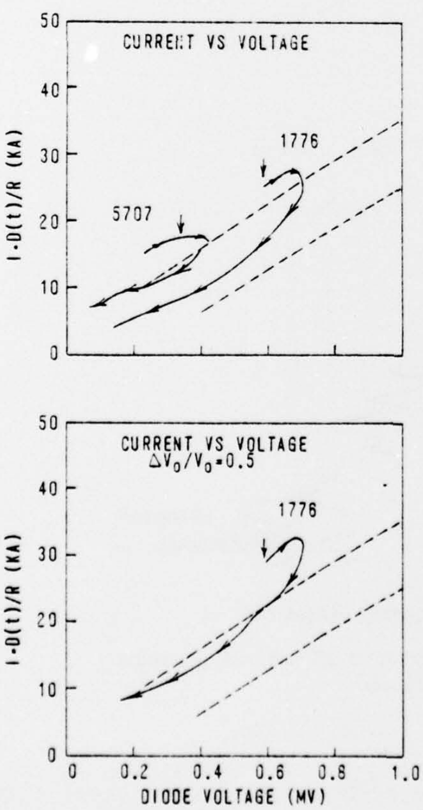
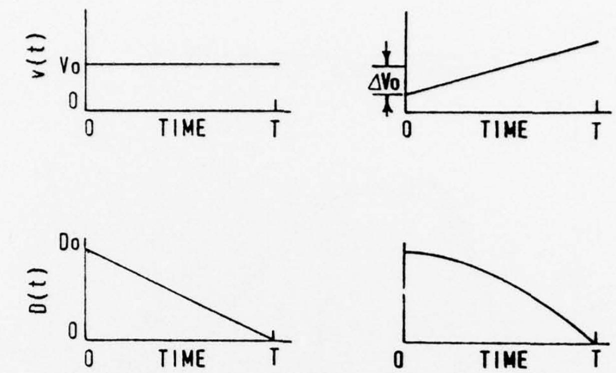


Fig. 5 — Normalized current calculated from the computer simulations versus voltage for the two shots. The upper graph uses the linear gap closure model and the lower graph uses the nonlinear model.

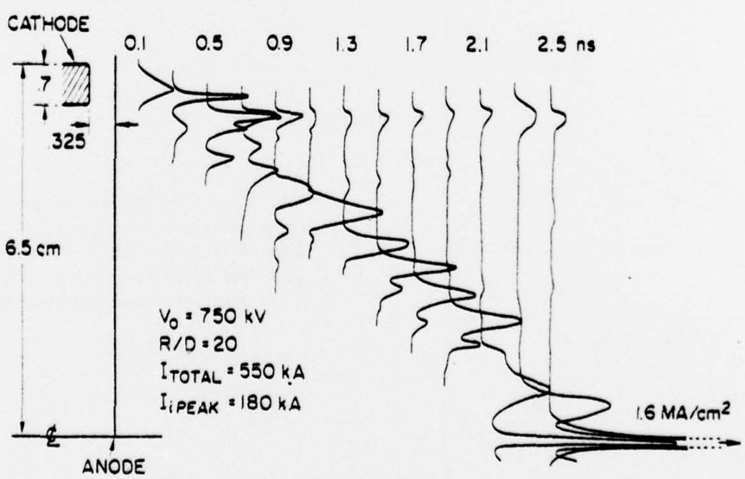


$D(t)/D_o =$
$1 - t/T$

$D(t)/D_o =$
$1 - t/T + \alpha t/T - \alpha t^2/T^2$

$\alpha = \Delta V_o/V_o$

Fig. 6 — The velocity and gap as a function of time for the two models.



RADIAL ELECTRON FLUENCE VERSUS TIME

Fig. 7 — Time dependent pinch formation shown in 2D computer simulation of very hollow cathodes.

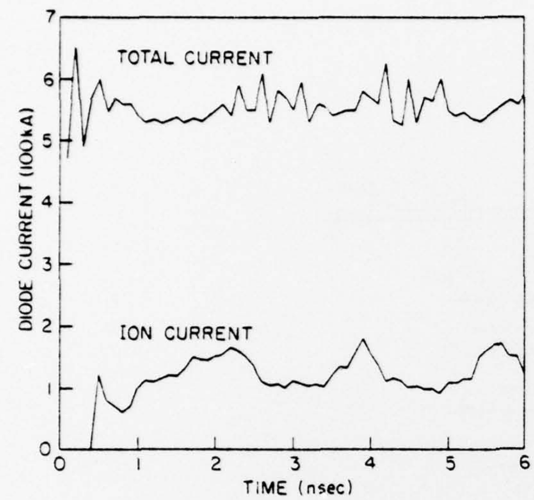


Fig. 8 — Total current and Ion current versus time from computer simulation.

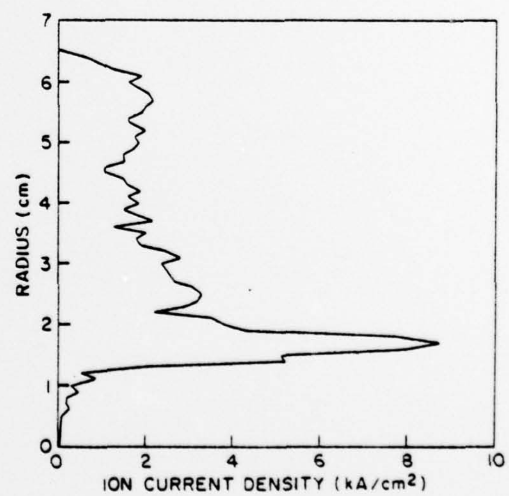


Fig. 9 — Ion current density collected in cathode plane from computer simulation.

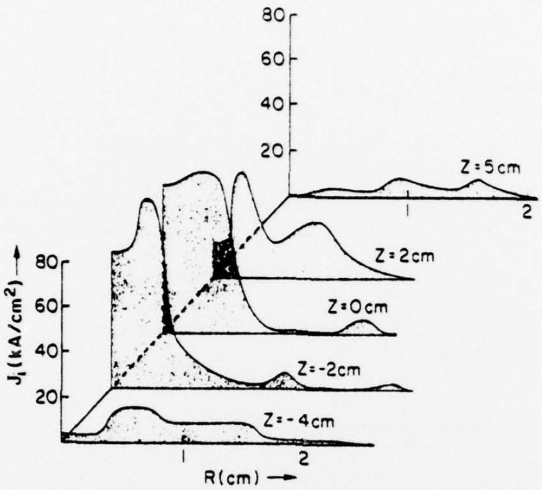


Fig. 10 — Radial proton current density profiles from time averaged computer simulation.

DNA DISTRIBUTION LIST 2/9/78

DEFENSE DOCUMENTATION CENTER
CAMERON STATION
ALEXANDRIA, VA 22314
(12 COPIES IF OPEN PUBLICATION, OTHERWISE 2 COPIES)
12 CY ATTN: TC

DIRECTOR
DEFENSE INTELLIGENCE AGENCY
WASHINGTON, DC 20301
1 CY ATTN: DTICI ROBERT I RUBENSTEIN

DIRECTOR
DEFENSE NUCLEAR AGENCY
WASHINGTON, DC 20305
1 CY ATTN: STVL
1 CY ATTN: TISI ARCHIVES
3 CY ATTN: TITL TECH LIBRARY
1 CY ATTN: RAEV

COMMANDER
FIELD COMMAND
DEFENSE NUCLEAR AGENCY
KIRKLAND AFB, NM 87115
1 CY ATTN: FCPR

DIRECTOR
JOINT STRAT TGT PLANNING STAFF JCS
OFFUTT AFB
OMAHA, NB 68113
1 CY ATTN: JSAS

CHIEF
LIVERMORE DIVISION FLD COMMAND DNA
LAWRENCE LIVERMORE LABORATORY
P.O. BOX 808
LIVERMORE, CA 94550
1 CY ATTN: FCPRL

UNDER SEC'Y OF DEF FOR RSCH & ENGRG
DEPARTMENT OF DEFENSE
WASHINGTON, DC 20301
1 CY ATTN: S&SS(OS)

COMMANDER
BMD SYSTEM COMMAND
P.O. BOX 1500
HUNTSVILLE, AL 35807
1 CY ATTN: SSC-TEN

DEP CHIEF OF STAFF FOR RSCH DEV & ACQ
DEPARTMENT OF THE ARMY
WASHINGTON, DC 20310
    1 CY ATTN: DAMA-CSM-N

COMMANDER
HARRY DIAMOND LABORATORIES
2800 POWDER MILL ROAD
ADELPHI, MD 20783
    (CNWDI-INNER ENVELOPE: ATTN: DELHD-RBH)
    1 CY ATTN: DELHD-NP
    1 CY ATTN: DELHD-RCC JOHN A. ROSADO
    1 CY ATTN: DRXDO-RBH PAUL A. CALDWELL
    1 CY ATTN: DRXDO-TI TECH LIB

COMMANDER
PICATINNY ARSENAL
DOVER, NJ 07801
    1 CY ATTN: SMUPA ND-N-E

COMMANDER
REDSTONE SCIENTIFIC INFORMATION CTR
U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, AL 35809
    3 CY ATTN: CHIEF, DOCUMENTS

COMMANDER
U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, AL 35809
    1 CY ATTN: DRCPM-PE-EA

COMMANDER
U.S. ARMY NUCLEAR AGENCY
7500 BACKLICK ROAD
BUILDING 2073
SPRINGFIELD, VA 22150
    1 CY ATTN: ATCN-W

COMMANDER
U.S. ARMY TEST AND EVALUATION COMD
ABERDEEN PROVING GROUND, MD 21005
    1 CY ATTN: DRSTE-EL

CHIEF OF NAVAL OPERATIONS
NAVY DEPARTMENT
WASHINGTON, DC 20350
1 CY ATTN: ROBERT A. BLAISE 604C4

COMMANDER
NAVAL ELECTRONIC SYSTEMS COMMAND
NAVAL ELECTRONIC SYSTEMS CMD HQS
WASHINGTON, DC 20360
1 CY ATTN: CODE 5032

COMMANDING OFFICER
NAVAL INTELLIGENCE SUPPORT CTR
4301 SUITLAND ROAD BLDG. 5
WASHINGTON, DC 20390
1 CY ATTN: NISC-45

OFFICER-IN-CHARGE
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MD 20910
1 CY ATTN: CODE WR43
1 CY ATTN: CODE WA501 NAVY NUC PRGMS OFF

COMMANDER
NAVAL WEAPONS CENTER
CHINA LAKE, CA 93555
1 CY ATTN: CODE 533 TECH LIB

AF WEAPONS LABORATORY, AFSC
KIRTLAND AFB, NM 87117
1 CY ATTN: CA
1 CY ATTN: ELC
1 CY ATTN: NT
1 CY ATTN: SUL
1 CY ATTN: DYP

HQ USAF/RD
WASHINGTON, DC 20330
1 CY ATTN: RDQSM

SAMSO/DY
POST OFFICE BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CA 90009
(TECHNOLOGY)
1 CY ATTN: DYS

SAMSO/IN
POST OFFICE BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CA 90009
    1 CY   ATTN: IND MAJ DARRYL S. MUSKIN

SAMSO/MN
NORTON AFB, CA 92409
(MINUTEMAN)
    1 CY   ATTN: MNNH

SAMSO/SK
POST OFFICE BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CA 90009
(SPACE COMM SYSTEMS)
    1 CY   ATTN: SKF PETER H. STADLER

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE LABORATORY
P.O. BOX 808
LIVERMORE, CA 94550
    1 CY   ATTN: L-18
    1 CY   ATTN: L-153
    1 CY   ATTN: JOHN NUCKOLLS A DIV L-545 (CLASS L-33)
    1 CY   ATTN: TECH INFO DEPT L-3

SANDIA LABORATORIES
P.O. BOX 5800
ALBUQUERQUE, NM 87115
    1 CY   ATTN: DOC CON FOR 3141 SANDIA RPT COLL
    1 CY   ATTN: DOC CON FOR 5240 GERALD YONAS

AVCO RESEARCH & SYSTEMS GROUP
201 LOWELL STREET
WILMINGTON, MA 01887
    1 CY   ATTN: RESEARCH LIB A830 RM 7201

BDM CORPORATION THE
7915 JONES BRANCH DRIVE
MCLEAN, VA 22101
    1 CY   ATTN: TECHNICAL LIBRARY

BOEING COMPANY, THE
P.O. BOX 3707
SEATTLE, WA 98124
    1 CY   ATTN: AEROSPACE LIBRARY

DIKEWOOD INDUSTRIES, INC.
1009 BRADBURY DRIVE, S.E.
ALBUQUERQUE, NM 87106
1 CY ATTN: L WAYNE DAVIS

EG&G, INC.
ALBUQUERQUE DIVISION
P.O. BOX 10218
ALBUQUERQUE, NM 87114
1 CY ATTN: TECHNICAL LIBRARY

FORD AEROSPACE & COMMUNICATIONS CORP
3939 FABIAN WAY
PALO ALTO, CA 94303
(FORMERLY AERONUTRONIC FORD CORPORATION)
1 CY ATTN: DONALD R. MCMORROW MS G30
1 CY ATTN: LIBRARY

FORD AEROSPACE & COMMUNICATIONS OPERATIONS
FORD & JAMBOREE ROADS
NEWPORT BEACH, CA 92663
(FORMERLY AERONUTRONIC FORD CORPORATION)
1 CY ATTN: TECH INFO SECTION

GENERAL ELECTRIC COMPANY
SPACE DIVISION
VALLEY FORGE SPACE CENTER
GODDARD BLVD KING OF PRUSSIA
P.O. BOX 8555
PHILADELPHIA, PA 19101
1 CY ATTN: JOSEPH C. PEDEN VFSC, RM 4230M

GENERAL ELECTRIC COMPANY
TEMPO-CENTER FOR ADVANCED STUDIES
816 STATE STREET, (P.O. DRAWER QQ)
SANTA BARBARA, CA 93102
1 CY ATTN: DASIAC

INSTITUTE FOR DEFENSE ANALYSES
400 ARMY-NAVY DRIVE
ARLINGTON, VA 22202
1 CY ATTN: IDA LIBRARIAN RUTH S. SMITH

ION PHYSICS CORPORATION
SOUTH BEFORD STREET
BURLINGTON, MA 01803
1 CY ATTN: H. MILDE

IRT CORPORATION
P.O. BOX 81087
SAN DIEGO, CA 92138
1 CY ATTN: R. L. MERTZ

JAYCOR
1401 CAMINO DEL MAR
DEL MAR, CA 92014
1 CY ATTN: ERIC P. WENAAS

JAYCOR
205 S. WHITING STREET, SUITE 500
ALEXANDRIA, VA 22304
1 CY ATTN: ROBERT SULLIVAN

KAMAN SCIENCES CORPORATION
P.O. BOX 7463
COLORADO SPRINGS, CO 80933
1 CY ATTN: ALBERT P. BRIDGES
1 CY ATTN: JOHN R. HOFFMAN
1 CY ATTN: DONALD H. BRYCE
1 CY ATTN: WALTER E. WARE

LOCKHEED MISSILES AND SPACE CO INC
3251 HANOVER STREET
PALO ALTO, CA 94304
1 CY ATTN: LLOYD F. CHASE

MAXWELL LABORATORIES, INC.
9244 BALBOA AVENUE
SAN DIEGO, CA 92123
1 CY ATTN: A. RICHARD MILLER
1 CY ATTN: PETER KORN
1 CY ATTN: ~~ALAN C. KOLB~~ Wayne Clark

MCDONNELL DOUGLAS CORPORATION
5301 BOLSA AVENUE
HUNTINGTON BEACH, CA 92647
1 CY ATTN: STANLEY SCHNEIDER

MISSION RESEARCH CORPORATION
735 STATE STREET
SANTA BARBARA, CA 93101
1 CY ATTN: WILLIAM C. HART
1 CY ATTN: CONRAD L. LONGMIRE

MISSION RESEARCH CORPORATION-SAN DIEGO
P.O. BOX 1209
LA JOLLA, CA 92038
(VICTOR A. J. VAN LINT)
1 CY ATTN: V. A. J. VAN LINT

NORTHROP CORPORATION
NORTHROP RESEARCH AND TECHNOLOGY CTR
3401 WEST BROADWAY
HAWTHORNE, CA 90250
(DESIRES ONLY 1 COPY OF CNWDI MAT)
1 CY ATTN: LIBRARY

NORTHROP CORPORATION
ELECTRONIC DIVISION
2301 WEST 120TH STREET
HAWTHORNE, CA 90250
1 CY ATTN: VINCENT R. DEMARTINO

PHYSICS INTERNATIONAL COMPANY
2700 MERCED STREET
SAN LEANDRO, CA 94577
1 CY ATTN: DOC CON FOR BERNARD H. BERNSTEIN
1 CY ATTN: DOC CON FOR CHARLES H. STALLINGS
1 CY ATTN: DOC CON FOR PHILIP W. SPENCE
1 CY ATTN: DOC CON FOR ~~IAN D. SMITH~~ Bernie Lippmann
1 CY ATTN: DOC CON FOR SIDNEY D. PUTNAM

PULSAR ASSOCIATES, INC.
11491 SORRENTO VALLEY BLVD
SAN DIEGO, CA 92121
1 CY ATTN: CARLETON H. JONES JR.

R & D ASSOCIATES
P.O. BOX 9695
MARINA DEL REY, CA 90291
1 CY ATTN: C. MACDONALD
1 CY ATTN: WILLIAM R. GRAHAM JR.
1 CY ATTN: LEONARD SCHLESSINGER

SCIENCE APPLICATIONS, INC.
P.O. BOX 2351
LA JOLLA, CA 92038
1 CY ATTN: J. ROBERT BEYSTER

SPIRE CORPORATION
P.O. BOX D
BEDFORD, MA 01730
1 CY ATTN: ROGER G. LITTLE

SRI INTERNATIONAL
333 RAVENSWOOD AVENUE
MENLO PARK, CA 94025
1 CY ATTN: SETSUO DDAIRIKI

SYSTEMS, SCIENCE AND SOFTWARE, INC.
P.O. BOX 4803
HAYWARD, CA 94540
1 CY ATTN: DAVID A. MESKAN

SYSTEMS, SCIENCE AND SOFTWARE, INC.
P.O. BOX 1620
LA JOLLA, CA 92038
1 CY ATTN: ANDREW R. WILSON

TEXAS TECH UNIVERSITY
P.O. BOX 5404 NORTH COLLEGE STATION
LUBBOCK, TX 79417
1 CY ATTN: TRAVIS L. SIMPSON

TRW DEFENSE & SPACE SYS GROUP
ONE SPACE PARK
REDONDO BEACH, CA 90278
1 CY ATTN: TECH INFO CENTER/S-1930

VOUGHT CORPORATION
MICHIGAN DIVISION
38111 VAN DYKE ROAD
STERLING HEIGHTS, MI 48077
(FORMERLY LTV AEROSPACE CORPORATION)
1 CY ATTN: TECH LIB

NRL CODE 2628 - 20 CYS

NRL CODE 6700 - 1 CY

NRL CODE ~~[illegible]~~ - 20 CYS (1 CY CLASSIFIED)
6750